Using Copulas to Model Complex Clouds

Contributors

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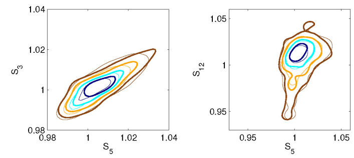
Research Highlight

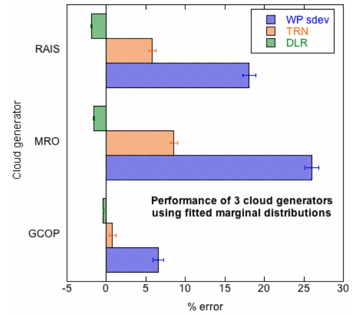
The realistic prediction of cloud cover and cloud properties by global climate models (GCMs) is a well-known limiting factor in the accuracy of today's climate predictions. Cloud prediction by GCMs is made difficult by the fact that the scale of cloud variability is often much smaller than the grid resolutions that are computationally available to them. Climate modelers address this scale problem by seeking to estimate the variability of the unresolved cloud properties in terms of the resolved scale properties such as temperature, moisture, and atmospheric motion. For example, the cloudy fraction of each layer of a grid column often has been estimated from the mean relative humidity of the layer. More recently, probability distribution functions (PDFs) have been employed to represent the spread of moistures that are unresolved by the model. The key parameters of these PDFs, such as the mean, variance, and skewness, must then be predicted by the model from resolved scale variables. Another difficult problem that affects radiation and precipitation processes is how to represent the geometrical overlap of clouds in different layers of the model, and by extension, the vertical correlations between the properties of clouds in these cloudy layers.

Our work aims at addressing all the above issues simultaneously by describing the joint horizontal and vertical variability in the unresolved properties of a GCM-sized grid column. To do this, we use generalized skewed distributions to fit the saturation ratio S (ratio of total moisture content to the saturation vapor content) and temperature (T) variability within each layer, and statistical functions called copulas to model the correlation of this variability between model layers. These copula functions are now in widespread use in financial modeling, but have not hitherto been used in atmospheric modeling. They are essentially joint cumulative distribution functions of the layer ranks of the variables of interest (e.g., S and T). In this paper, we develop the theory of their use to model warm (liquid) clouds by using synthetic data from an ARM intensive operational period (IOP) run of the Goddard Cumulus Ensemble (GCE) high resolution cloud model. We demonstrate that S-only copulas are mostly sufficient to capture the cloud fraction overlap, water path statistics and radiation field characteristics of a complex liquid cloud field. We propose a specific type of copula, the “Gaussian copula,” as appropriate for cloud parameterization, and as a basis for developing a cloud generator that can produce cloudy subcolumns for use in radiation algorithms operating stochastically (e.g., McICA). The Gaussian copula is intuitive, flexible, and provides a pathway for incorporation in GCM cloud schemes via parameterization of its correlation matrix. It also performs well for our case study as evidenced by the results in the accompanying figures.

We believe that this new theory and its implementation as a cloud generator has significant potential in both GCM cloud modeling and in the assimilation



Contours containing (brown-80%, orange-60%, cyan-40%, and blue-20%) of the joint inter-layer S probability, such that the probability densities within each contour are larger than those outside. Thick contours are from the GCE thin contours are from our Gaussian copula. The separation of layers is 256 m (left panel) and 1652 m (right panel). The expected reduction in inter-layer correlation with increasing layer separation is observed (i.e., contours aligned more along the diagonal for 256 m).



Percent biases in domain standard deviation of water path (WP sdev), transmitted solar flux (TRN) and downwelling longwave radiation to the surface (DLR) of three cloud generators (GCOP=Gaussian Copula, MRO=Geleyn and Hollingsworth Maximum Random Overlap, RAIS=a total water version of the Raisanen et al. generator) relative to exact GCE values (ICA calculations for the radiative quantities). S-only marginal fits and 100 generator realizations were used with the bias spread shown as error bars.

of high resolution cloud data being provided by modern Earth observing satellites and ground-based platforms such as those operating for the ARM Program. Future work will focus on using such data to better model the marginal distributions of S and T, to parameterize the correlation matrix of the Gaussian copula, to test other copulas such as the Student-t copula, and to extend our methodology to ice and mixed-phase clouds.

Reference(s)

Norris PM, L Oreopoulos, AY Hou, WK Tao, and X Zeng. 2008. "Representation of 3D heterogeneous cloud fields using copulas: Theory for water clouds." Quarterly Journal Royal Meteorological Society, 134(636), doi:10.1002/qj.321.

Working Group(s)

Cloud Modeling